their activities, forest growth would decline and eventually come to fluctuate about a much lower average level of productivity. So their contributions need to be much better understood and managed. Methods for deciding whether soil communities are indeed fully stocked with the proper numbers and kinds of different organisms to get maximal nutrient and energy turnover are needed. For example, are there adequate numbers of large, soil-litter mixing species such as the various kinds of worms, craneflies, termites, and so on? If not, should some new species be introduced to the forest system?

Finally, the role of invertebrates in forest stream and river systems needs to be better addressed. They, along with micro-organisms, are the foundation for all sport fishery resources in our Nation's forests.

Protecting Forest Resources From Fire

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Fire has always been with us. It has periodically burned forests and grassland as long as flammable vegetation has existed on earth. Today in the United States, on the average, 250,000 wildfires burn almost 5 million acres of forest, brush, and grass-covered lands each year. Protection services cost more than $0.5 billion annually. Losses approach $2 billion. These costs do not include the services of thousands of volunteer fire departments, nor do they include the expenses of the many city fire departments that fight fires on undeveloped lands within or near their jurisdictions. Yet few activities, public or private, have had such a high degree of success as fire prevention and management.

The average size of wildland fires has been reduced from 120 acres in 1925 to about 20 today, in spite of the fact that the risk of fires starting, as determined by various types of land use, has increased more than 10 times.

Research has had an important hand in this success. At the beginning of this century, foresters found themselves managing a wild, remote area in which the causes, behavior, and effects of fire were poorly understood, if at all.

Early fire research was essentially engaged in management science—trying to determine the needs of a fledgling fire-control organization and developing a policy for its activities.

Since World War II, fire research has expanded to include the physical, biological, and social sciences. Current programs draw heavily on the fields of meteorology, engineering, administration, and operations research.

Forest Service Research Organization

While the U.S. Department of Agriculture's (USDA) Forest Service conducts fire research at six of its nine forest experiment stations, the nature of many fire research projects requires the support of specialized scientific facilities and equipment such as wind tunnels and combustion chambers. Most of these specialized facilities are located at three forest fire laboratories located at Macon, GA; Missoula, MT; and Riverside, CA. Two out of every three Forest Service fire scientists work at one of the laboratories, resulting in an important pooling of talent and skills. Each laboratory has two principal responsibilities: to perform applied and basic fire-related research to meet national needs and to conduct other research, mostly of an applied nature, on current fire problems peculiar to the part of the country where the laboratory is located.

The laboratories work together on a national program of forest fire research in cooperation with other forest experiment stations; universities; scientific groups; and private, State, and Federal agencies.

While much of the research is aimed at today's problems, fire scientists also are directing their efforts toward solving the problems of the 1990's and 2000's. Scientists don't do this alone, but in cooperation with others in the scientific community and the user group. The latter includes Federal, State, and local fire-management officials—those people who must put the results of the research to practical use.

Scientists and users, applying futuring techniques, have jointly identified the following nine high-priority areas where much future research will be concentrated.

Fire Management in the Wildland and Urban Interface. A major demographic trend from urban to suburban living, begun after World War II, has greatly expanded the wildland and urban fire problem. This area, where people build their homes and live in the midst of flammable forest vegetation, occurs at thousands of locations across the Nation. In these areas, people and their property are at risk from forest fires, and the loss has been increasing rapidly as more and more people build in these high-hazard areas. In Virginia, for example, the number of homes exposed to wildfire loss has increased fourfold in the last 5 years. Major loss of life is possible—in fact, inevitable.

The task of protecting lives and property from fire in the wildland and urban interface area poses one of the most critical and elusive problems for fire researchers and managers today. If fire managers are to save property and lives, they need better knowledge and information on how to help homeowners, community planners, and builders design fire-safe communities.

Integrated Fire Behavior and Fire Danger Rating System. Fire managers use one analytical system to estimate fire danger for day-to-day planning and another for on-the-fire tactical decisionmaking. Even experienced firefighters get the two systems confused. Fire danger rating and site-specific fire behavior prediction are both based on knowledge of the physics and chemistry of wildland combustion. But current systems for predicting fire danger and behavior involve different resolutions of time and geographical area. Research

needs to provide a single system that would accommodate the full range of requirements and save considerable money, time, equipment, and training.

Prescribed Fire for Wilderness Management. Current Forest Service policies allow fire to resume a more natural role in those areas set aside as part of the National Wilderness System. More than 75 years of fire protection, however, have materially changed wilderness ecosystems and allowed an accumulation of forest fuel that is difficult to manage. Land managers look to research to provide ways to define the natural role of fire in wilderness and criteria for deciding when planned or unplanned ignitions (such as lightning fires) are appropriate.

Evaluation of Aircraft for Fire and Forest Management. Wildland management agencies own or lease a wide range of aircraft types for their fire and forest-management operations. These range from light observation helicopters to high-elevation, remote-sensing aircraft to jet transports for fire crew transport.

Managers need means for evaluating the effectiveness of various types of aircraft. They need to translate the operational requirements of fire and forestry activities into desired aircraft performance. Research can help provide the guides to use these aircraft in the most cost-effective manner.

Social, Political, and Economic Values in Fire Management. How do you measure the worth of a sunset? It is difficult perhaps, but not impossible. Over the past decade, major progress has been made in developing economic analysis methods that relate investments in fire protection to the anticipated changes in resource values resulting from wildfires. In spite of this progress, it is still difficult to incorporate political and social considerations into fire-management planning processes. As a result, decisionmakers have limited ability to evaluate alternatives in terms other than economic efficiency. Social and political attributes are still treated qualitatively, often resulting in inconsistent and sometimes unacceptable programs.

Improved understanding is needed of the relationships among social, political, regulatory, and other factors with respect to decisions about fire-management investments.

Fire Suppression Productivity and Effectiveness. Foresters have been fighting fire for 80 years, yet they still do not have all the answers about how fast or well they do the job—partly because the job is much more complex than it used to be.

The most important reason is that almost every task must be evaluated in terms of cost effectiveness. Fire research must provide an improved understanding of the factors governing fireline building and holding success, tradeoffs and interactions among different fire control actions, and a better understanding of human physiology and motivation.

Alternatives to Herbicides. Use of chemical herbicides to prepare sites and control vegetation for the establishment and release of forest stands has become progressively less practical as a result of undesirable environmental effects and stringent regulation. Land management agencies and private forest enterprises are faced with significant reductions in commercial forest productivity—25 to 35 percent or more—without adequate site preparation and effective means of controlling competing vegetation. Alternative methods of vegetation management, including the use of prescribed fire, are needed to im-

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Scientists at the USDA Forest Service's fire laboratory in Missoula, MT, conduct instrumented test fires in a specialized combustion chamber.

Where urban and wildland areas meet, fire is a rapidly increasing problem. In some parts of the United States, the number of homes at risk to woodland fires has increased fourfold in the past 5 years.

prove regeneration success and enhance growth and yield of established stands.

Effects of Atmospheric Change on Forest Health and Productivity. The effects of changes in the atmosphere on forest health and productivity are not always known. Some weather impacts are sudden and dramatic such as windthrow in a storm. Drought or excessive moisture also are readily observable. Some effects caused by gradual changes in normal conditions are not as obvious but are generally understood. Examples are early and late frosts and impacts of recurring severe winters.

Yet another category involves climatic changes because of increasing levels of pollutants, including particulates, carbon dioxide, and acid rain. The effects may include degradation of visibility, lowered water quality, and reduced tree growth.

The opportunity for managers to deal with these effects is severely restricted by a lack of knowledge about the processes which translate atmospheric changes into forest effects.

Long-Term Forecasting of Fire Weather Severity. Fire management depends on maximum mobility of firefighting resources to provide satisfactory forest fire protection while restraining cost. Effectiveness of mobility is directly related to ability to determine where and when resources will be needed. Prudent financial management requires no overinvestment during normal periods of fire occurrence, but, when existing resources are strained, mobilizing an adequate number of firefighters and their equipment must be possible. Managers need reliable weekly, monthly, and seasonal fire weather severity forecasts.

Research must develop systems to provide information on geographic variation of fire severity potential on at least a biweekly basis for resource allocation purposes.

Fire research, like most activities of government, can expect budget reductions over the next few years. By concentrating efforts on anticipated high-priority needs, however, fire research should continue to make valuable contributions in the future as it has in the past.